Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.7, No.8, 2017

www.iiste.org

# On-Site Sanitation and Its Effects on the Groundwater Resources of Nyali-Bamburi-Shanzu and Diani-Chale, Kenya

Saeed Mwaguni*[1] Elias Ayiemba[2] John Onyari[3]

1.Department of Environment and Health Sciences, Technical University of Mombasa, Tom Mboya Avenue, P.O. Box 90420-80100, Mombasa, Kenya

2.Department of Geography and Environmental Studies, University of Nairobi, P.O. Box 30197-00100, Nairobi, Kenya

3.Department of Chemistry, School of Physical and Biological Sciences, University of Nairobi, P.O. Box 30197-00100, Nairobi

**Abstract**

This paper has analyzed the effects of on-site sanitation systems on groundwater and the impact this has to public health in the human settlements and tourist establishments of Nyali-Bamburi-Shanzu and Diani-Chale areas –two, very important tourist destinations in the Kenya coast. The pit latrine and septic-tank/soakage pit are the two main systems used for containing human waste in the settlements. These two on-site sanitation systems constitute the main source of potential contamination to groundwater and its consequences in the two areas. Hence, the boreholes and wells in the two study areas were located on a map using a GPS to serve as the sampling points. Water from these sources was analyzed for nutrient and feacal contamination in the laboratory. The nutrient contamination was established through the levels of total ammonia, nitrates/nitrites, and phosphates. These were determined using calorimetric methods; while the 5-tube, 3- dilution, Most Probable Number (MPN) technique was used for the evaluation of the levels of total Coliforms and *Escherichia Coli* (E-coli) parameters. The study was designed with a strategy that captured the effects and impacts of the contaminants with the varying tourist seasons and rainfall pattern. Results of the study revealed that the level of nutrient and micro-bacteria contamination varied with location, distance, tourist seasons and rainfall pattern relative to the contaminating sources. Water sources located within the human settlements and beach hotels –and within short distances to the contaminating sources exhibited elevated levels of nutrients and micro-bacteria; water sources located down-stream the human settlements revealed even higher contamination levels, indicating more input of nutrients and micro-bacteria probably through underground flow and seepage into the water aquifers –likely through cracks in the coral rock formation characteristic of the two study areas. The results of the study lead to the conclusion that on-site sanitation systems, though sanctioned for human waste disposal, may not be suitable in areas dominated by coral geology basement, particularly so when stringent observance of regulations and standard required in the construction of the waste disposal systems are not adhered to. Out of the conclusion, it is recommended that a shift towards innovative approaches in human waste management need to be advanced and pursued as a matter of policy in environmental management.

**Keywords:** On-site sanitation, water contamination, nutrients, micro-bacteria, Total coliform, E. coli

## 1. INTRODUCTION

This paper presents the effects of on-site sanitation on groundwater resources and its implications on public health in the Nyali-Bamburi-Shanzu and Diani-Chale, two tourist beach destinations in the Kenya Coast that are very dependent on groundwater for potable uses. In this area, residents use pit latrines and septic tank-soakage pit systems for excreta disposal. This study was carried out upon observations that the sanitation systems were generally not constructed to standard requirements and their maintenance was poor. The systems, in particular the pit latrines, were shallow, poorly constructed, and therefore prone to overflowing, posing a threat to groundwater contamination, with the potential effects of the spread of water borne diseases, with impact to human health. This scenario, is undermining environmental quality in the human settlements, contributing to the loss of aesthetic appeal from these neighborhoods' in sustaining beach tourism development. Acknowledged that human settlements and tourism developments require huge amounts of water –water that is wholesome, and of good quality, to meet the quality objective of safeguarding health and safety; such a requirement cannot be realized in such an environmental setting. Thus, water quality requirements cannot be assured in areas where sanitation management is on-site. To understand this situation reasonably, the study located and mapped the groundwater sources in the study area, and through the known indicators of water pollution, established the contamination levels, and tracked this with the health impacts associated with the situation.

The background to the analytical assessment resides on the established composition of groundwater bodies. The natural occurrence of ammonia through the breakdown of nitrogenous compounds in groundwater are generally below 0.2 mg per liter. Where this limit is exceeded, then anthropogenic input is the sources of such elevation, mainly through discharges from fertilizer in farmland activities, municipal and industrial wastewater, including leachates from waste disposal sites. Other sources of ammonia in water would include weathering of igneous rocks, land drainage, and plant and animal debris. Found as nitrate ion –a common form of combined nitrogen existing in natural waters, its level seldom exceed 0.1 mg per liter as $NO_3$-N, (UNESCO/WHO/UNEP, 1992). Where sanitation is on-site and the sewage management systems, not of sound standard works, ammonia from sewage can enter water bodies, elevating its concentration beyond the geogenic levels. This provides an indicator of water pollution from feacal matter. Nitrite concentrations in groundwater on the other hand, are generally as low as 0.01 mg/liter $NO_2$-N, and rarely go above 1 mg/liter $NO_2$-N. Therefore, the presence of high *nitrite* concentration in water bodies is indicative of bacterial activity, often from recent sewage discharges. The presence of nitrites in water signifies water that is of unsatisfactory microbiological disposition. Determined in a combined form as nitrate and nitrite, it gives the general indication of the level of nutrient in water and therefore a measure of the level of water pollution. Consequently, nutrient determination in water is one of the parameters in most water quality status surveys (UNESCO/WHO/UNEP, 1992). Phosphorous is the other nutrient found in water. It is one of the essential nutrient for living organisms and occurs in water bodies either in solution, or, as particulate matter. It is mostly detected in water in the dissolved form of orthophosphates, or polyphosphates; or bound organically, as phosphate. Phosphorous changes continuously in-between these forms as a result of decomposition, synthesis of its organically bound forms, and oxidation of the inorganic forms. As it is continuously absorbed by plants, it is hardly found in high levels in groundwater, limiting its average level as $PO_4$-P to about 0.02 mg/liter (UNESCO/WHO/UNEP, 1992). High concentrations of phosphates in groundwater are therefore also indicative of anthropogenic inputs and largely from wastewater of domestic origin, where detergents containing substance are used; from industrial discharges; or, from surface run-off. Elevated levels of phosphates in water cause eutrophication with loss of aesthetic appeal of water body for on-water recreational activities and also has impact on aquatic life.

Coliform bacteria and E. coli, the other indicators of water contamination do not occur in water naturally. Found to be universally present in faeces of animals and human beings the presence of coliforms in water bodies is associated with the presence of human waste, or effluent rich in nutrient. Coliforms are easy to detect, and to enumerate, but their determination is wrought with many complications, including the existence of many forms of the bacteria. Found in a multiplicity of sources, limits its applicability as an indicator of pollution, but has nevertheless been used as a universal indicator for pollution by sewage. Residing on particles suspended in water columns that float freely, their measurements vary notoriously as the amount measured is dependent on the amount of particles in the water column - a condition that can vary with distances and time intervals even in water exhibiting uniform conditions. The values of coliform measured can also vary with rainfall with immense fluctuations. *Escherichia coli (E-coli),* also found in sewage and treated effluents, can also easily find its way into natural water bodies and in soils. Its detection indicates the potential presence of dangerous pathogens in water. This is of concern since *E-coli* has been associated with many water borne diseases. This paper presents historical information to offer data as an avenue for comparison with data from the current situation to re-enforce the need for action towards implementation of modern sewage treatment methods.

The importance of maintaining good water quality both from freshwater bodies and from the marine environment cannot be emphasized. Human settlements need freshwater that is wholesome and free from contamination for domestic needs. Tourism on the other hand thrives in areas with plentiful water for drinking and clear water waters of the marine environment for on-water recreational activities. Areas that are water deficient, like Kisauni in Mombasa are prone to water borne diseases, Mwaguni, 2000, while tourists are known to abandon destinations that have degraded from pollution related causes, Biliana et al., 1998. Turkey's coastal areas are endowed with natural beauty replete with various resources OECD, 1992. However, these resources have been degraded due to a number of causes, including urbanization, sharp increase in population density and pollution. Rapid growth of tourism in Turkey's coastal areas doubled the population pressure on the coastal zone, resulting in many environmental and socio-economic effects with pollution of coastal waters threatening swimming, public health, fisheries and biodiversity. Similar effects, resulting from tourism development have been reported in Thailand, where its beach resorts at Pataya, Phuket and Ko Samui were negatively impacted by rapid development of tourism infrastructure, undermine its coastal water resources (Dubois 1989; Bunpapong & Ausavajitanon 1991.

## 2. Study area and Research Methods

### 2.1 Study area

The two study areas of NBS and Diani-Chale are located north and south of Mombasa in Kenya's coast respectively. A characteristic feature of these two areas is the change of use of land from traditional to urban uses, represented by the development of human settlements, commercial establishments, beach hotels and tourism related infrastructure.

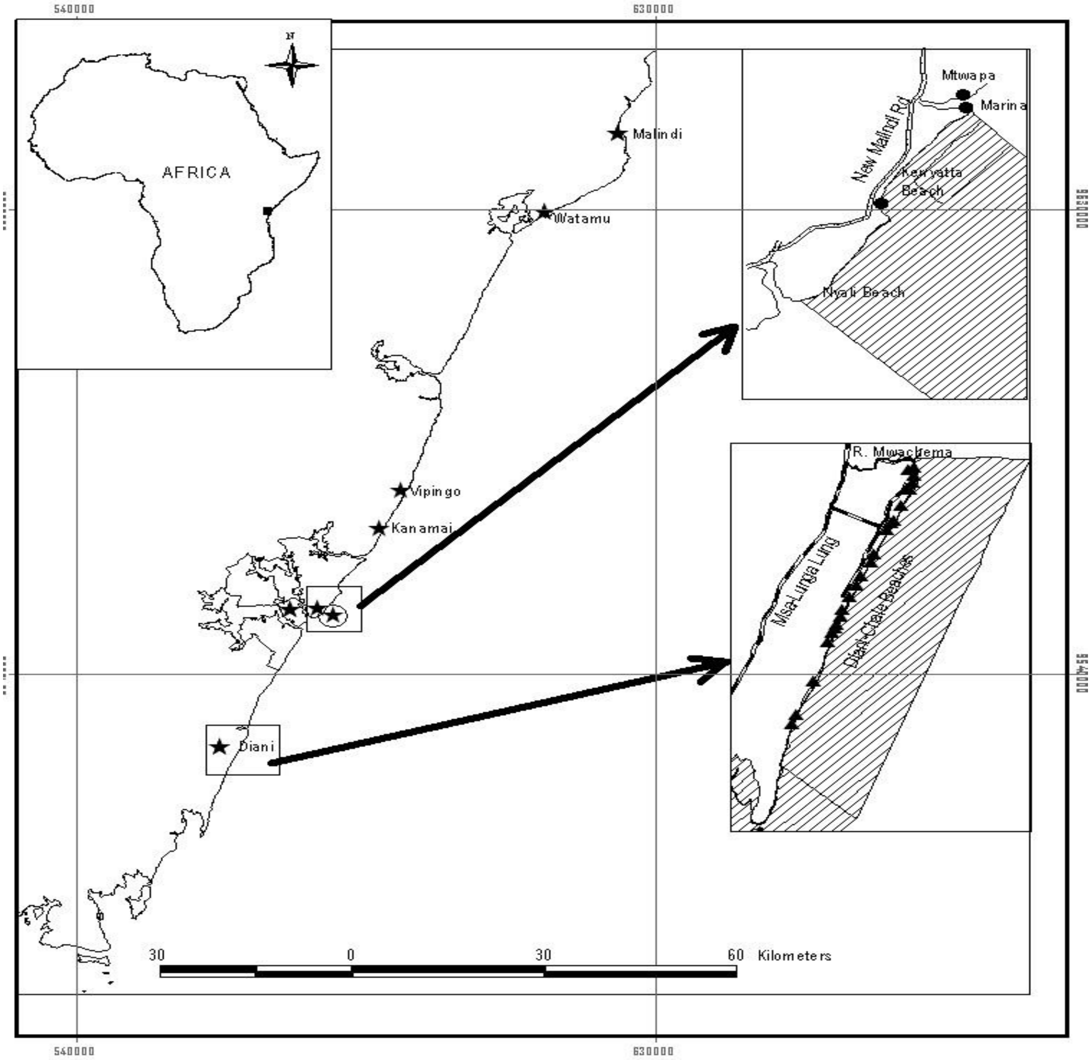


Fig. 1: Map of Location of the two Study Areas, Source, McClanahan et al., (2004)

Human settlements in the two study areas have increased more than three-fold in the last 20years. Major residential areas in the NBS area include the Kisauni housing estates of Mlaleo, Mwandoni, Mishomoroni, Mtopanga, Shanzu, Kisimani, and Bombolulu. Other residential areas include Mnazi Mmoja, Kongowea, VOK, Mwembe Legeza and Utange (Mwaguni, 2013). Tourist hotels located in this segment include Reef Hotel, Bahari Beach, Silver Beach, Mombasa Beach, Nyali Beach, silver beach, Malaika, Dolphin, and Serena Beach. In Diani-Chale, the major human settlements are Gombato, Ukunda, Diani, Bongwe, Mwabungo and Kinondo. Major tourist hotel establishment are Indian Ocean Beach Club, Southern Palms, Diani Resort, Leopard, Leasure Lodge, Diani Sea Resort, Jadini, Aficana, Nomad, Safari, Pappilon, Baobab, White Rose, Neptune, Pine Woods and Chale Club. Taken together, the change in land use came about with little regard to consideration for the development of appropriate infrastructure to manage human waste in areas largely dependent on groundwater for potable purposes. The study therefore looks at the situation to determine the resultant effects on groundwater quality for the scenario.

## 2.2 Materials and Methods

Various methods were utilized in generating information for this study. They included locating the groundwater sources, and sampling and analysis of groundwater for chemical and microbiological indicators of pollution. The water sources –boreholes and wells that were sampled positioned using a hand held Geographical Position System. The sampling strategy was spread to capture data during low, medium and peak tourist periods, which mirror the dry and wet seasons. It targeted water sources within human settlements, hotel establishment, and in location representative of a rural set-up or those that were sparsely habited. For chemical analysis –three samples were taken once per month from 21 borehole/well in each study areas. The samples were collected in 100ml capacity, acid washed bottles and preserved using 2 drops of chloroform. Samples for microbiological analysis were collected in sterile glass bottles with caps, and all consequent handling of the samples was done in sterile conditions to avoid contamination. The samples were stored at $4^0$ C in iceboxes and transported to the laboratory for analysis on the same day.

For nutrient analysis, methods modified from Parsons et al., 1984, and APPA, 1995 were used. Data on the nutrients concentration covered the non-ionized $NH_3$ and the ammonium cation $NH^+_4$ and reported as mg/l: ($NH_4$-N); Nitrite + Nitrate as {($NO_2^-$ + $NO_3^-$)-N} and orthophosphate as ($PO_4^{3-}$-P). Microbiological examination of the water samples for Total Coliforms and *Escherichia Coli* (E-coli) was done using the 5-tube, 3- dilution, Most Probable Number (MPN), technique. Samples were inoculated into the Mac Conkey broth and incubated at $37^0$ C for 24-48 hours for total coliform count. Gas positive tubes were sub-cultured in brilliant green lactose bile broth and incubated for 48 hours, and the tubes that tested positive for indole production in tryptone water were considered positive for E-coli. The Most Probable Numbers were computed from Probability tables. All chemicals used in these analyses were of analytical grade.

## 3 Results

### 3.1 GPS Location of the Groundwater Sources in NBS and Diani-Chale

Table 1:Location of the Boreholes/Wells in Nyali Bamburi Shanzu

| No | Name | BH/W | Easting | Northing |
|---|---|---|---|---|
| 1 | Umoja Residence | W | 575605 | 9553459 |
| 2 | Masjid Bidalla | W | 575618 | 9555714 |
| 3 | Snake Valley | BH | 575772 | 9554575 |
| 4 | Islam Ali -2 | BH | 575951 | 9555824 |
| 5 | Islam Ali -1 | BH | 575962 | 9555714 |
| 6 | Coast Hauliers | W | 576419 | 9552302 |
| 7 | Freretown Mterere | W | 576661 | 9555138 |
| 8 | Freretown Jerald | W | 576739 | 9555194 |
| 9 | Coast Hauliers -2 | W | 576820 | 9555644 |
| 10 | Katisha | BH | 576828 | 9555989 |
| 11 | Masjid Mgongeni | W | 576972 | 9555647 |
| 12 | Kisimani Stage | W | 577149 | 9555193 |
| 13 | Masjid Swafaa | W | 577370 | 9554772 |
| 14 | Masjid Hussein | W | 577429 | 9557702 |
| 15 | Masjid Noor | W | 578163 | 9558652 |
| 16 | Utange R.C | W | 579196 | 9559922 |
| 17 | Voyager Hotel | B | 579302 | 9554196 |
| 18 | Utange Nalan | W | 579830 | 9561071 |
| 19 | Utange Pendua Viungani | W | 580455 | 9560536 |
| 20 | Masjid Dar al Kam | W | 580633 | 9560234 |
| 21 | Shimo Annex | B | 581163 | 9562231 |

Table 2: Location of the Boreholes/Wells studied in Diani-Chale

| No/Name | Type | Latitude | Longitude | Easting | Northing | Depth (m) |
|---|---|---|---|---|---|---|
| 1. Mwakamba 1 | OW | 4°15.957' | 39° 40.311' | 574575.7 | 9550593.7 | 16 |
| 2. Minazi 15 | CW | 4° 15.883' | 39° 35.666' | 565965.2 | 9528621.7 | 19 |
| 3. House Itaha | CW | 4° 15.903' | 39° 35.698' | 566025.1 | 9528585.2 | 20.5 |
| 4. Nesola | CW | 4° 16.015' | 39° 35.725' | 566074.8 | 9528382.8 | 22 |
| 5. Jardin BH 6 | BH | 4° 19.333' | 39° 34.092' | 563049.5 | 9522268.1 | 22 |
| 6. Seacrest Sch | BH | 4° 19.305' | 39° 34.008' | 562894.2 | 9522323.5 | 19 |
| 7. Jardin BH 3 | BH | 4° 19.431' | 39° 34.061' | 562991.7 | 9522084.7 | 22 |
| 8. Safari B/H BH4 | BH | 4° 19.353' | 39° 34.227' | 563299.2 | 9522231.5 | 21.5 |
| 9. Safari B BH 1 | BH | 4° 19.713' | 39° 33.945' | 562777.2 | 9521568.6 | 21 |
| 10. Madago Nur. Sch | OW | 4° 21.337' | 39° 33.014' | 561052.8 | 9518585.5 | 28 |
| 11. Galu Pri. Sch | BH | 4° 21.221' | 39° 32.199' | 559546.1 | 9518788.8 | 24 |
| 12. Digirika 1 | BH | 4° 20.542' | 39° 32.274' | 559685.7 | 9520042.2 | 40 |
| 13 Magutu Gigigi | BH | 4° 17.981' | 39° 33.428' | 561823 | 9524756.0 | 23 |
| 14. Mwembe Chitasa | BH | 4° 17.267' | 39° 33.771' | 562458.7 | 9526082.0 | 30 |
| 15. Bwagamoyo | OW | 4° 19.070' | 39° 33.074' | 561166.8 | 9522749.2 | - |
| 16. Ukunda Poly | BH | 4° 18.040' | 39° 33.170' | 561345.7 | 9524645.9 | - |
| 17. Muuyugutu | W | 4° 18.018’ | 39° 33.375’ | 561725.3 | 9524700.9 | 36 |
| 18. Nchitolapo | BH | 4° 17.085’ | 39° 33.228’ | 561454.6 | 9526414.4 | 32 |
| 19. Mwembe Baa | BH | 4° 16.562’ | 39° 33.128’ | 561270 | 9527372.8 | 33 |
| 20 Mwamanga Pri. | BH | 4° 16.388’ | 39° 32.481’ | 560073.9 | 9527705.3 | 30 |
| 21.Noor Mosque | OW | 4° 17.243’ | 39° 33.462’ | 561887.2 | 9526120.0 | - |

 

### 3.2 The Nutrient Contamination in N-B-S Groundwater Sources

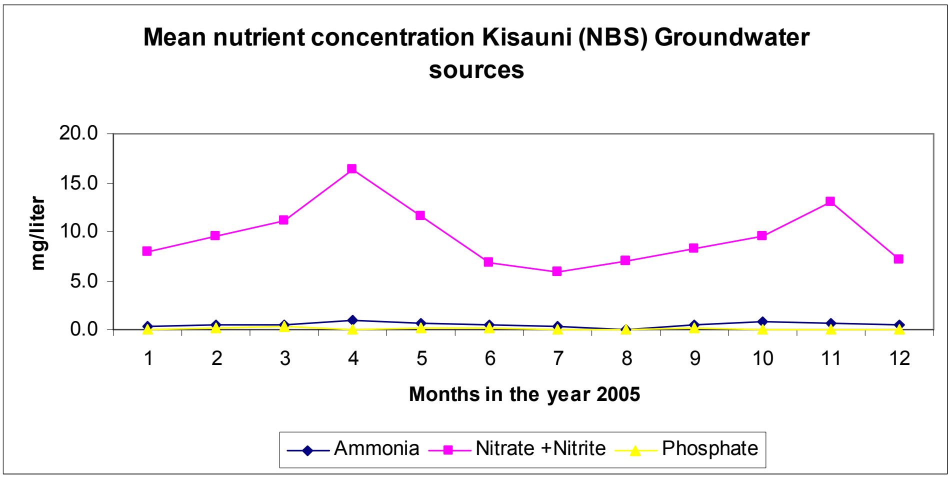


Figure 2(a): Mean nutrient concentration NBS Groundwater sources,

The mean nutrient concentration in the NBS groundwater sources is presented in Figure 2(a). It varied depending on the location of the individual water source. As the ammonia and phosphate concentrations could not be interpreted at the scale of the above figure, a re-scaling was done to enable interpretation of the results for these two nutrients. These results are shown in Figures 2b and 2c that follow.

Natural levels of nitrates in groundwater hardly exceed 0.1 mg $l^{-1}$, while that for nitrites can be as low as 0.001 mg $l^{-1}$. Potable limit for nitrate in drinking water is 10 mg/litre. For ammonia, the natural levels are usually below 0.2 mg per litre, potable limit is 1.5 mg/litre. For phosphorous, the natural levels in groundwater is about 0.02 mg/litre $PO_4$-P, while the potable limit is 5.0 mg/litre, UNESCO/WHO/UNEP, (1992). From Figure 4(a), the combined nitrate + nitrite, concentration values ranged between 6 ± (4.5) to 16.3 (± 6.0) mg $[NO^-_3+NO^-_2]$–N/litre. For ammonia and phosphate, the concentration was between 0.3 ± (0.17) to 0.9 ± (0.36), mg $l^{-1}$ $NH_4$-N; and 22.8 ± (11.9) to 123.5 ± (84.0) µg/$l^{-1}$-$PO^{4-}$-P, respectively, Figures 4(b) and 4(c).

Some water sources recorded nitrate concentrations way above the recommended potable limit of 10 mg $NO_3$-N/liter. Seven of the 21 water sources sampled from the human settlements in NBS yielded nitrate + nitrite concentration of between 12 to 50 mg-N/l. Water sources located downstream of the large inland human settlements with high population density, represented by the groundwater source at the Voyager Hotel along the Nyali Beach gave elevated nutrient values. Thus, the water point at the Voyager beach represented a classical example of downstream contamination from on-site sanitation systems through groundwater flow. As the natural concentration of ammonia in groundwater hardly goes beyond 0.2 mg $NH_4$-N $l^{-1}$, the elevated values indicate contamination from external sources.

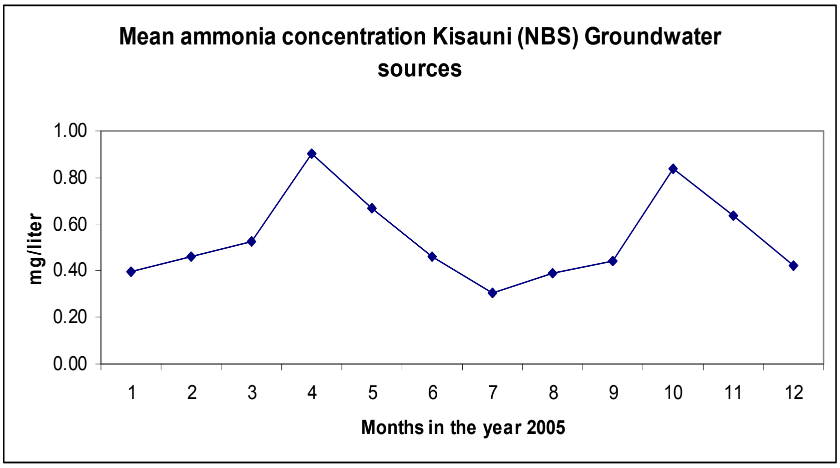


Figure 2(b)

 

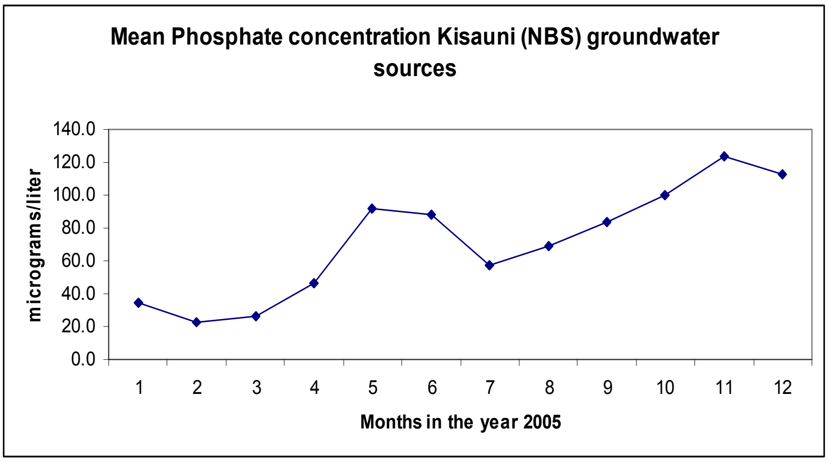


Figure 2(c)

For phosphorous, the concentration levels obtained were very low, and within the accepted limit for water designated for potable purposes, limit, with this its levels, causing no little concern.

On account of seasons, relatively higher concentrations of nitrate/nitrite were recorded just before the onset of the rains in April, (8 to 30 mg $l^{-1}$, Fig. 2(b), but lower figures were obtained in June-July, (2-20 mg $NO_3$-N/$l^{-1}$.), Figure 2(c). Eighteen water sources sampled in July produced water within the set standard for potable supplies for nitrate concentration, indicating the superior effect of recharge and dilution. The results of distribution of nitrate + nitrite concentration in (NBS) study area groundwater sources during both the dry and wet weather periods of the year are presented in simple surface model maps shown in Figures 3(a) and 3(b).

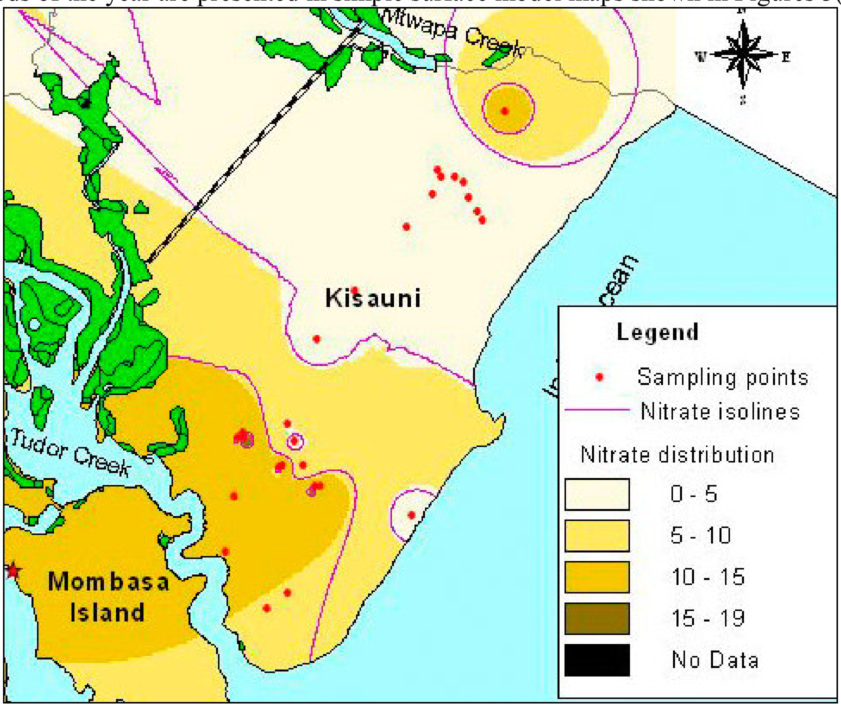


Figure 3(a): Groundwater Nitrate + nitrite concentrations, NBS April, 2005

 

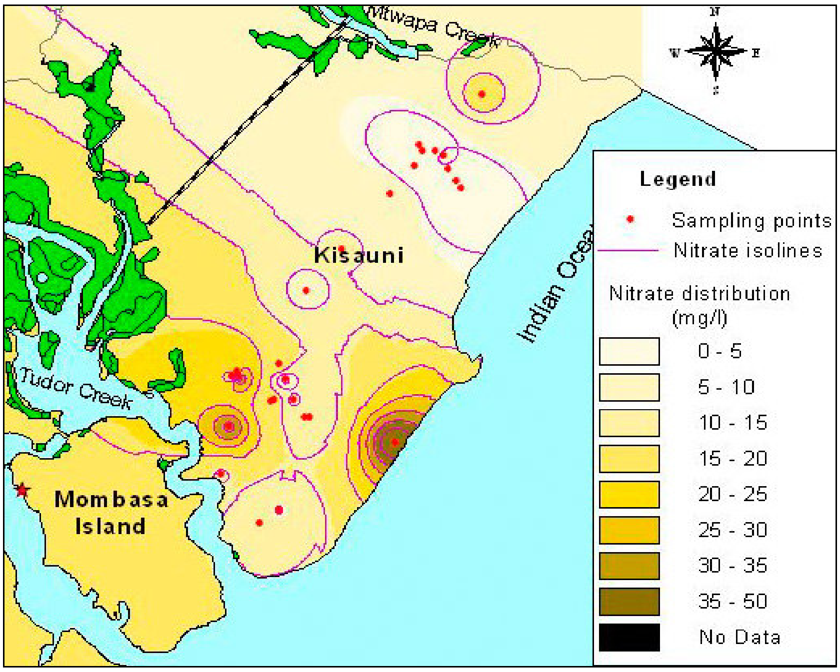

Figure 3(b): Groundwater nitrate + nitrite concentrations, NBS, July 2005

### 3.2.1 Nutrient Contamination in Diani-Chale Groundwater Sources

The mean nutrient concentration of the groundwater sources of Diani-Chale is shown in Figure 4(a) and 4(b). This also varied with source of the water point.

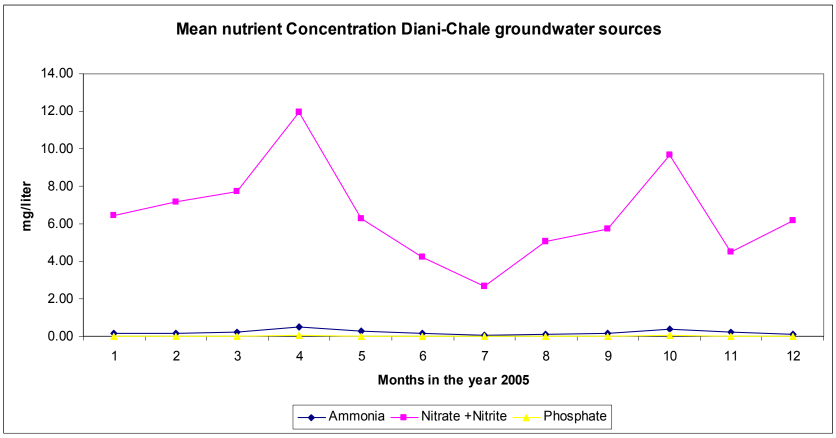

Figure 4(a): Mean Nutrient Concentration, Diani-Chale groundwater sources, 2005

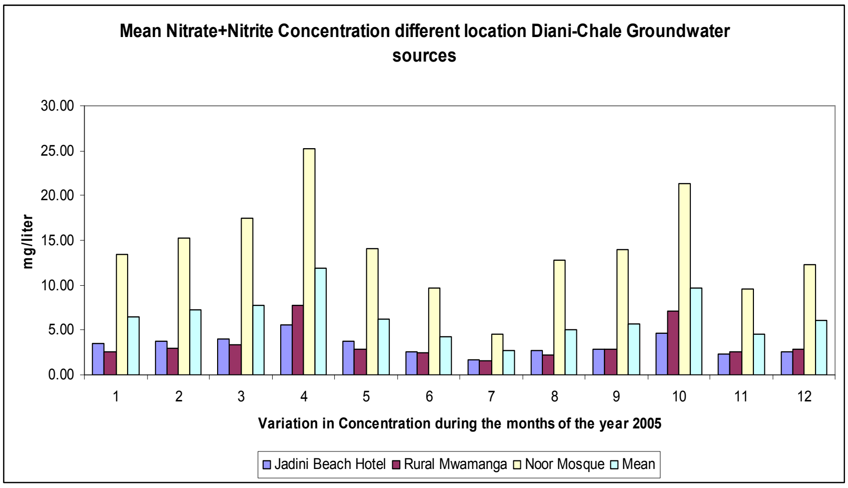

Figure 4(b) Variation of mean nitrate + nitrite with water source, (2005) While the mean *nitrate+ nitrite* ranged between 2.66 ± (1.51) to 11.92 ± (7.39) mg $NO_3$-N $l^{-1}$, this varied with the location of source of the water point as shown in Figure 5(b), but with the highest concentration, recorded at the on-set of the rains. However, as aquifer recharge takes place, dilution lowers the mean concentration to its lowest signal of 2.66 mg $l^{-1}$ in July. The nitrate + nitrite concentration of between 6.5 to 7.7 mg $l^{-1}$ was recorded during the long dry period, while that of 5.07 to 5.73 mg $l^{-1}$ was reported during the short dry spell.

Water source located in rural areas like Mwamanga with a thin population density gave the lowest nitrate + nitrite concentrations of between 1.6-3.4 mg $l^{-1}$ with a flushing peak of 7.7 mg $l^{-1}$. Similarly the Jadini Beach Hotel well-water source located in a forested area gave low nitrate + nitrite concentrations, fluctuating between 2.5 to 4.15 mg $l^{-1}$. On the other hand, the Noor Mosque water point situated in a densely populated area had high nitrate + nitrite signals ranging from 4.5-17.4 mg $l^{-1}$ with a flushing peak value of 25.2 mg $l^{-1}$. This once again shows that the further away from human settlement a water source is, the lower the nitrate + nitrite signals.

Water points representing the settled area i.e. those at Madogo Nursery, Galu Primary, Mwembe Chitasa, Bwagamoyo, Ukunda Youth Polytechnic, Muuyugutu, Nchitolapo, Mwembe Baa and Noor Mosque, had a mean nitrate + nitrite value of 8.5 mg/litre, while that of the forested areas, represented by Jadini 1 and 2 wells, Safari 1 and 2 wells, and the water source serving the Hillcrest School, had a mean value of 2.93 mg $l^{-1}$.

The results obtained for contamination of water sources in unsewered settlements are not surprising. The effect of unsewered sanitation on groundwater quality has been demonstrated by the rising nitrate concentration in public supply wells, elsewhere; Greater Buenos Aires, and Burmuda, (Foster, et al., 1987 are examples. Though this problem does not affect large cities with assured sources of surface water supply for potable purposes, small towns which rely on groundwater for potable supplies are impacted. This case confirms the situation for the study areas, where direct pollution of the wellhead by users, takes place, and water contamination by nitrates is a serious problem. Being areas of coral geology with thin soils; fissures/cracks allow rapid percolation of contaminants underground into the shallow water tables, explaining the results obtained.

For the nutrient *ammonia,* the average concentration ranged from 0.08 ± (0.04) to 0.49 ± (0.12) mg $NH_4$-N $l^{-1}$, Figure 5(a). In this study area, water sources located within human settlements and those in the forest showed higher levels of ammonia. The mean concentration of this nutrient also showed the same characteristics of the rural and urban settings as described for the nitrate+nitrite parameter. The surge up and down of the ammonia concentration was also dictated by weather conditions with the highest values recorded at the on-set of the rains.

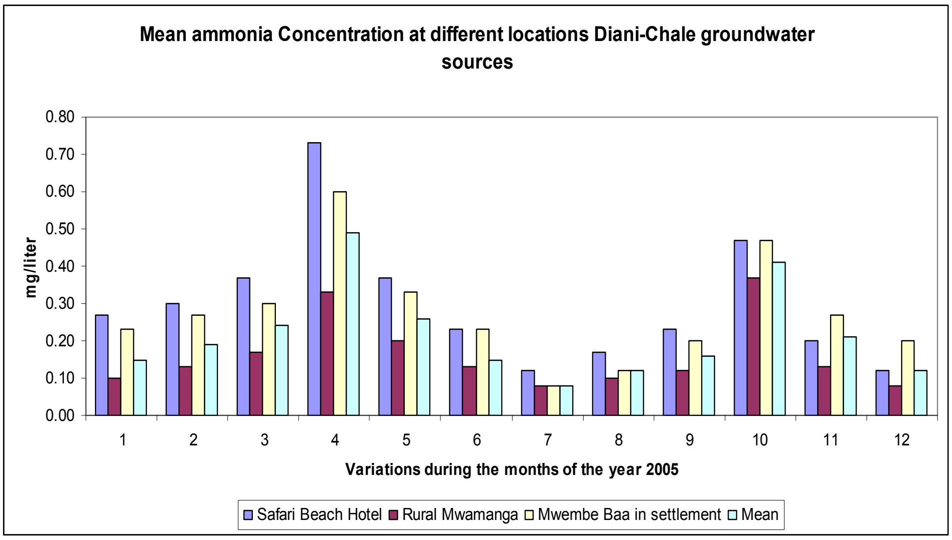


Figure 5(a): Mean ammonia concentration at different locations in the Diani-Chale study area, (2005)

Examples of the variation of ammonia concentration by location of source of the water point shown in Figure 5(a) above are explained as follows: at Mwembe Baa, a densely populated area, the ammonia concentration was generally above 0.3 mg $l^{-1}$. At Mwamanga, which represents a rural setting, it was below 0.2 mg $l^{-1}$. Groundwater source located in the forest to the hinterland of the beach hotels represented by the Safari and Jadini Beach hotels also had somehow high ammonia concentration levels, about 0.2 of mg$l^{-1}$. The elevated ammonia levels observed in the water sources located in the forest could be due to the nitrogen fixation cycle by plants leading to the consequent release of ammonia into the ground by the roots. The mean yearly concentration of *phosphates* ranged from 16.3 µg ($PO^{4-}$P) $l^{-1}$ in January but steadily rising through February, March to reach a flushing peak at 34.9 µg $PO^{4-}$P $l^{-1}$ in April, Figure 5(b).

 

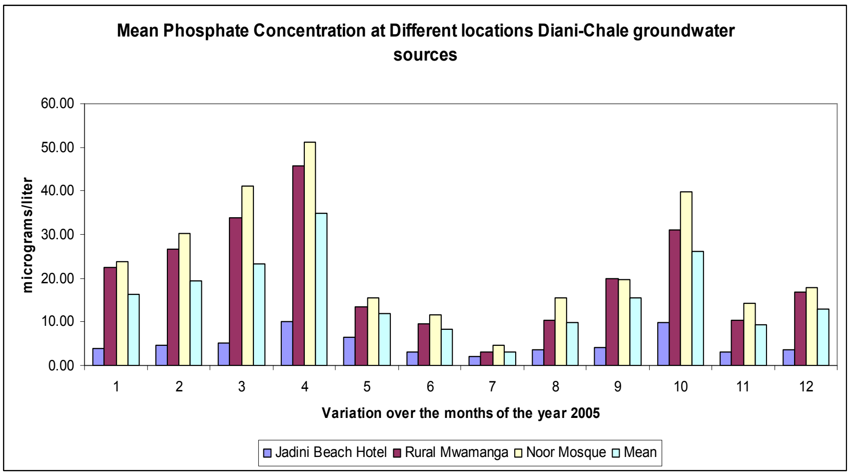


Figure 5(b): Mean Phosphate Concentration at different locations Diani-Chale Groundwater sources, 2005

Both Noor Mosque, (representing a densely populated area) and Mwamanga (representing a rural set-up with a scattered population) gave interesting results, where, the phosphate concentration levels were higher than the mean yearly average for the study area. In these areas the mean phosphate concentration ranged from 3-4µg $l^{-1}$ at the minimum, to 45-51µg $l^{-1}$ on the higher side.

In the forested area in the immediate hinterland of the tourist beach hotels represented by the Jadini, Safari Beach and Hillcrest School water points, the mean phosphate concentrations ranged from 3.70µg $l^{-1}$ in January rising to 4.85µg $l^{-1}$ in March, attaining a flushing peak at 11.20 µg $l^{-1}$.in April before dipping to 2µg l-1 due to quick recharge of the ground aquifers by rainfall.

The low levels of phosphate concentration in the water- points located in the forest areas can be explained in two ways, one is that there are few anthropogenic activities in the forest to generate any meaningful amounts of phosphates; two, phosphorous material, if any, introduced on the surface is actively taken up by plants as part of the metabolism process.

## 3.3 Microbiological Contamination in Groundwater Sources

This sub-section presents the results of the microbiological examination of the groundwater sources in the two study areas.

### 3.3.1 Microbiological Contamination N-B-S Groundwater Sources

The tables below show the variation of microbial contamination in the groundwater sources of Nyali-Bamburi-Shanzu of the Kisauni District, Mombasa County.

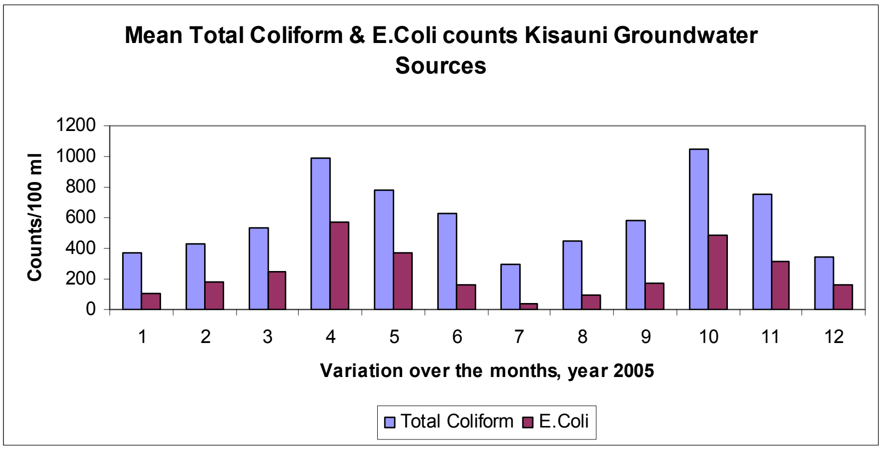


Fig 6: Mean Bacterial counts: Number /100ml, Total coliform & E. coli, NBS groundwater sources, (2005).

The mean Total coliform bacteria and E. coli concentration, Number/100ml, in the Kisauni (NBS) groundwater sources is shown in Figure 6. The means ranged from 294 ± (198.3) – 1050 ± (865.8) for total coliform bacteria, and 35 ± (6.8) – 575 ± (920.2) for E. coli. As most of the groundwater sources are located within the human settlements, this explains the high levels of bacterial contamination.

Same as for the nutrients, the signals of both Total Coliform and E. coli counts variations are dictated by the weather conditions. At the onset of the rains in April, the bacterial counts shoot to the highest signals in the groundwater sources. However, as aquifer recharge takes place, the signals dipped down on dilution with rain water. During the dry weather conditions the counts showed slight increase with intensifying dry weather conditions.

### 3.3.2 Microbiological Contamination Diani-Chale Groundwater Sources

The mean Total coliform and E. coli counts in the groundwater sources of the Diani-Chale study area are given in the figure 7. The mean total coliform counts ranged from 75 ± (66.5) – 470 ± (565.1), while the mean E. coli recorded was between 2 ± (3.5) – 35 ± (24.5). As was the case in the NBS study area, the counts fluctuated with the rainfall pattern, attaining peak counts when the rains just begin, dipped to a trough, when it is wettest, and slowly increased with intensification of dry weather. Both dry weather seasons, long and short, incidentally correspond with the peak and mid-tourist seasons, which may explain the increase in bacterial signals.

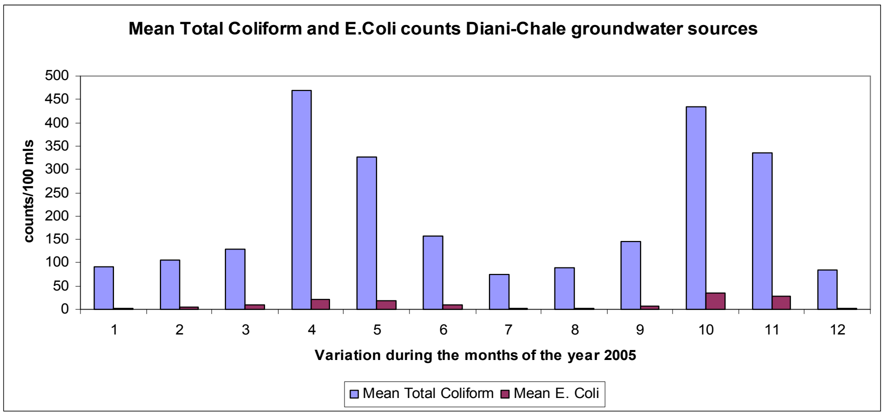


Figure 7: Mean Bacterial counts number/100ml of total coliform and E. coli in Diani-Chale groundwater sources (2005)

The bacteria signal sequence thus, correlates with both the weather and fluctuation in human numbers as represented by the local population and the visiting tourists. At the levels of coliform and E. coli detected, not a single water point met the potable standard for human use except when chlorinated as observed with the water sources at Noor Mosque and Mwembe Chitasa, which became potable on dosing with chlorine. This action also distorted the results of the concentration of the bacteria levels recorded during the study. But when the effectiveness of the chlorine vanished, the water sources reverted to their non-potable status, an indication of external continuous source of contamination from the human dwellings.

## 4 Conclusions

The on-site sanitation systems in the two study areas are not very effective in containing the human wastes. As a result, the levels of nutrient and microbiological concentration in groundwater were at times higher than is acceptable in water used for potable needs. The levels also varied depending on the location of the sampling site. Water sampled within human settlements and near the beach hotels showed higher levels of contamination. Groundwater seeping on the beach from the hinterland also showed elevated contamination. Groundwater sources located down-stream human settlements were more polluted than those away from such an environment, showing the influence of coral geology and movement of water as a media of transport of contaminated water through such rock formation.

The generally higher levels of contamination in Nyali-Bamburi-Shanzu than in Diani-Chale are explained by the former being more urbanised than the later as both share the same on-site systems for managing human waste in similar a rock basement formation, which promote in the same way both recharge from rainfall and transport of contaminants.

This study concludes that the on-site sanitation system are not very effective in containing human wastes in area where the geological rock formation promotes the spread of contaminants. It is also concluded that new technological approaches to human waste management are needed. This is in line with Kenya's Policy Principles on sanitation provision. Unfortunately, efforts on the ground comprise extension of existing networks not the adoption of new technologies. Therefore in order to address this, the recommendations that follow, need to be pursued.

## 5 Recommendations

i) Kenya needs to strengthen existing policies on water and sanitation and build capacity of institutions;
ii) The country needs to adopt the policy on integrated coastal zone management as this policy provides a holistic approach to coastal planning and development;
iii) There is urgent need to develop Master Plans to guide development of coastal areas, correcting bad situations where planning for service infrastructure has often not been taken into account within the land use changes taking place, if human health and tourism development is to be sustained;

iv) Non-water borne sanitation or low cost-water consuming technologies could be introduced to conserve water and hence minimize the volume of wastewater generated;
v) Finally, cost recovery measures must be enhanced through enforcement of consumption based charges, connection fees, effluent discharge fees, and discharge permit. In effecting this, a tariff regime that considers issues of equity should be adopted as an effective approach for generating finance to cater for innovative technologies in waste management.

## References

1. Billiana, Cicin-Sain & Knetch, Robert W.: Integrated Coastal and Ocean Management –Concepts and Practices, Island Press, 517pp, 1998
2. Bunpapong, S., and S. Ausavajitanon: Saving what is left of tourism development at Patong Beach, Phuket, Thailand. InCoastal Zone '91, ed. O. T. Magoon, H. Converse, V. Tippe, L. Tobin, and D. Clark 1688-1697. New York: American Society of Civil Engineers, 1991
3. Dubois, R., & E. L. Towle: Coral harvesting and sand mining management practises. In Coasts: Coastal Resources Management –Development case studies ed J. R. Clark, 443-508. Washington DC.: US Department of the Interior, National Park Service, and U.S. Agency for International Development, 1985
4. Forster, N. M. & J. H. Archer: Introduction: The National Marine Sanctuary Program –Policy, education, and research. Oceanus 31 (1): 5, 1988
5. Mwaguni, S. M. The Effects of Tourism and Related Human Settlement on the Conservation of Coastal Water Resources, University of Nairobi, 2008
6. Parson, T. R., Maita Y., Lalli, C. M.: A manual of Chemical and biological methods of seawater analysis, Pargamon Press, pp 173, 1984
7. UNESCO/WHO/UNEP: Water Quality Assessments, a Guide to the Use of Biota, Sediments and Water in Environmental Monitoring, Chapman and Hall, 585pp, 1992